NORTH AMERICAN REVIEW.

No. CCCCXIX.

OCTOBER, 1891.

CAN WE MAKE IT RAIN?

BY GENERAL ROBERT G. DYRENFORTH AND PROFESSOR SIMON NEWCOMB, LL. D.

WITH the steady movement of our population westward the flood of immigration has ascended the valleys of our western rivers, and is now rapidly spreading out over the vast stretches of unwatered prairie land which comprise the great plains of the western portions of Nebraska, Kansas, the Dakotas, Wyoming, and Montana, the Llano Estacado of Texas, and the arid plateaus of the mountain States and territories.

As civilization pushes its way further into the semi-arid regions, the subject of irrigation and artificial means of procuring a sufficient water-supply grows in importance, and forces itself, whether or no, upon the attention of the country at large ; for, as prospers the western farmer, so, to a large degree, prosper both the West and East.

If moderately watered, the great plains and the table-lands of the Cordilleras would afford more valuable lands for the production of cereals and fruits than the entire area of all lands under cultivation in the States east of the Mississippi, while, if droughts in the valley of the Missouri and upper Mississippi could be prevented, the productiveness of those regions would be vastly increased.

In many of the valleys and hilly districts of the West exten-

sive systems of irrigating dams and canals have been constructed at an expense of many millions of dollars, by which thousands of miles of land have already been reclaimed from drought and converted into farms and plantations of marvellous productiveness. In the valley of the Pecos River, in New Mexico, a region which was considered but a desert until a few years ago, it is not an uncommon achievement to produce four crops of vegetables in a season by means of the artificial-irrigation systems. Such results are also obtained at many points on the famous Staked Plains, wherever a small garden is put under cultivation, and irrigated by means of bored wells and windmill pumps. For these prairie lands are richly fertilized with deposits of phosphates and vegetable decay, the accumulations of centuries, which have not been washed out by frequent heavy rains, as is the case in other localities.

Irrigation is successfully employed in many valleys and mountainous regions; but no system has yet been devised which could be introduced upon the plains on an extensive scale without very great expense, since there is no opportunity for constructing elevated dams and reservoirs upon the level prairie lands.

If, then, this vast territory, which might be so prolific, is ever to be utilized for anything more than furnishing a meagre subsistence to a few head of cattle to the square mile, some method different from any now in practice must be introduced to provide for a sufficient and regular watering of the land. It has been in view of such facts as these that scientists have at various times advanced the proposition of producing rainfall in times of drought, and in arid regions, by artificial means. Various methods have been suggested; but nearly all have aimed to produce rainfall by the same general means, viz., by mingling currents of air differing considerably in temperature and humidity, and so causing the moisture to be condensed and finally precipitated by the cooling of the warmer current, and the consequent lessening of its capacity for holding moisture in suspension. It is believed that nearly all rainstorms originate in this manner, as is stated by Professor Silliman in his "Principles of Physics," page 656, as follows: "Rain is generally produced by the rapid union of two or more volumes of humid air differing considerably in temperature; the several portions, when mingled, being incapable of absorbing the same amount of moisture that each would retain if

they had not united. If the excess is great, it falls as rain; if it is slight, it appears as cloud. The production of rain is the result of the law that the capacity of air for moisture decreases in a higher ratio than the temperature."

A large part of the water which falls on this country as rain, watering our crops and feeding our great rivers, comes to us in the great equatorial current, which arises far to the southwest over the Pacific Ocean, from which it receives its great burden of moisture, and, flowing to the northeast, bears it directly over the most arid portions of our country and Mexico. However, as it flows on over these regions uninterrupted and undisturbed, it seldom precipitates its moisture until it meets the polar current, which flows over the Eastern States in a southwesterly direction. This current is invariably much cooler, and whenever it comes in collision with the warm, moisture-laden current from the southwest, clouds begin to form from the condensation, and precipitation of rain generally follows.

If in some way the equatorial current can be deflected into cooler currents while passing over the arid regions of the Southwest and West, rain should follow almost as surely as in any other locality. The problem seems to resolve itself into the question, "Can this be done, and if so, how most economically?"

As long ago as the time of Plutarch it was "a matter of current observation that unusually heavy rains fall after great battles," and it is not impossible, according to the theory of the commingling of air currents, that such rains might have been produced by the great battles of ancient times. Let ten thousand Greeks march into battle chanting their "pæans" and shouting their "allallas," beating time meanwhile on their shields, while a hundred thousand Persians are advancing against them, continually shouting their terrible battle-cries; then let the great armies rush together with the tumult of clashing swords and shields, the fierce shouting of the multitudes, the hoarse death-cries and shouts of victory, and surely the sound waves rising from such a din will literally shake the heavens, and are capable of producing no insignificant effect among the volatile currents of the upper air. Moreover, the heat generated from the struggling masses and the moisture evaporated from their perspiration would exercise a decided influence in disturbing the equilibrium of the atmospheric conditions.

In 1837, Professor Espy, at that time a well-known scientist, proposed a method of compelling nature to loose the moisture which she holds suspended aloft. His plan was to kindle great fires which would produce a powerful upward current of hot air, and this, "rising to a great height, where, owing to the diminished pressure, it would expand, by the expansion would be cooled, thereby condensing and eventually precipitating its moisture."

The Australian Government proposed in 1884 to make a test of Espy's theory; but when Mr. H. C. Russell, the government astronomer of New South Wales, demonstrated that it would require 9,000,000 tons of coal burned daily to increase by 66 per cent. the rainfall at Sidney, where the average humidity is 73, the project was forthwith abandoned.

Long before Espy's time, the facts had already been noticed that heavy artillery-firing was frequently followed by rain. Napoleon was the first man who is reported to have noted this phenomenon, and he took advantage of its regular occurrence in ordering the manœuvres of his troops.

Later, during the Franco-Prussian War, which opened in the summer of 1870, the fact that rain fell after battles was again brought to notice and widely discussed by European scientists. A letter published in the New York *Evening Post* of October 5, 1870, from which the following extract is taken, shows that much attention had been given to the subject on the other side of the Atlantic. The letter is dated Frankfort-on-the-Main, September 14, 1870.

> "Since the commencement of actual hostilities between Germany and France—that is, from about the first week in August to the present time—we have had in this part of Germany scarcely a day without rain, generally continuous, and often accompanied with thunder-storms. This phenomenon has called the attention of the German press to the subject, and some valuable historical facts connected therewith have been brought to light; and there appears to be little doubt, judging from the data on hand, that many storms and rains which we have had in Germany for the past six weeks—a most unusual thing at this season here—have been brought on by the cannonading and firing of small arms in Alsace and Lorraine."

During our late Civil War the same phenomenon repeatedly occurred, and came to be one of the factors in the case to be considered by a general when planning his movements on the eve of an engagement.

In 1870, contemporaneously with the publications concerning

the rains in France and Germany, Mr. Edward Powers, of Delavan, Wis., a civil engineer of wide experience and observation, published a collection of most interesting statistics concerning the sequence of rainstorms after battles, in a volume entitled "War and the Weather." Mr. Powers had been convinced early in the Civil War not only that the concussion of heavy cannon-firing produced rain, but that such a result might be effected at any time without unreasonable expense, considering the value of rain in times of drought.

From the statistics published in Mr. Powers's book, it is found that heavy rains followed almost every engagement of any importance during the Civil War, and, so far as can be ascertained, the same phenomenon was common during the Mexican War upon the arid cactus plains of that country.

A notable instance of its occurrence during the Mexican War was at the battle of Buena Vista, fought on the 22d and 23d days of February, 1847, in the midst of the dry season in that region. The facts, as they occurred on the second day of that battle, as related by Brevet Major-General H. W. Benham, of the United States Engineers, are as follows:

Between 8 and 10 A.M. the artillery was engaged in heavy firing, and between 11 and 12 o'clock a "most violent rain" fell. In the afternoon the cannonading was resumed, and in about two hours after it ceased "another violent shower of rain fell." "And what I consider the *satisfactory proof*," says General Benham, "that this was caused by the shocks to the atmosphere produced by the cannon-firing, is that no rain had fallen in that vicinity for many months previously—I was told six or eight months—and none fell, *as I know* was the case, for three or four months after the battle, as I continued at that position."

The battles of Palo Alto, the siege of Monterey, Contreras, Churubusco, Molino del Rey, and Chapultepec were all fought during the dry season, which in Mexico is very severe, and each of these battles was followed by heavy rains. In his little book, "War and the Weather," Mr. Powers mentions 198 battles of the Civil War, including every battle of importance so far as the writer of this article has discovered, which were immediately followed by rain, as he has definitely ascertained. These storms were generally heavy, but varied somewhat in proportion to the magnitude of the engagements.

One or two extracts from letters received by Mr. Powers from army officers concerning the subject of "War and the Weather" may be of interest as showing the opinion which was held on the subject by those who had the best of reasons to remember the rains, which often served to render their route of march an unfathomable quagmire, or chilled them as they lay in bivouac after an exhausting day of fighting, or possibly on the field of battle among the wounded.

STATE OF MAINE, EXECUTIVE DEPARTMENT,
AUGUSTA, December 12, 1870.

MY DEAR SIR: My Adjutant-General has sent me your letter referring to the effect of heavy firing on the atmosphere leading to storms and rain. It is a most interesting matter. The *fact* of such sequences (if they may be called so without begging the question) I have often noticed. Certainly a heavy storm of rain occurred after the great battles of Antietam, Fredericksburg, Chancellorsville, Gettysburg, the Wilderness, Spottsylvania, Bethesda Church (Cold Harbor), Petersburg, Five Forks, etc.; and often, I well remember, in what we called small engagements (though they would be called battles in Europe), such as the fight on the "Quaker Road," March 29, 1865, for a late instance, in which there was a sharp, concentrated fire of infantry and artillery for a couple of hours, a very heavy rain would surely follow. This fact was well noticed, and is well remembered by many a poor fellow who, like myself, has been left lying, desperately wounded, after such engagements—for these rains are balm to the fever and anguish of the poor body that is promoted to the list of "casualties." I am sure that you will find my testimony confirmed by the recollections of every soldier.

(*Governor*) JOSHUA L. CHAMBERLAIN,
Late Brev. Maj.-Gen. Commanding 1st Div., 5th Corps.

BLOOMINGTON, ILL., December 13, 1870.

MY DEAR SIR: In reply to your favor of the 10th, not only has it been my experience that rain follows soon after every heavy cannonading, but that this was very generally conceded and understood in the army, and acted upon by the soldiers in preparing for it after every battle. I remember, particularly, that in the garrison at Lexington, Mo., when water could not be had, it was urged by myself and other officers encouraging the men to hold out for a few hours, and that the cannonading would bring rain to quench their thirst; and it did bring rain, but it found us without means to catch it in sufficient quantities. There are large numbers of soldiers in your city who will remember this circumstance and the wringing of their blankets to get water.

. . . .

The inauguration of Governor Hahn at New Orleans was accompanied by cannonading and the noise of musical instruments and anvils, infantry firing, etc., and was soon followed by very heavy rain. When the rebel ram ran by the city, the cannonading, only for a few minutes, was followed by rain. The passage of the forts at Mobile Bay, the bombardment of Fort Gaines, afterwards of Fort Morgan; again of Spanish Fort and Blakely; the landing of our troops at Pascagoula and firing of a few shots with field-pieces on the shore; the battle of Sterling Farm, and the fighting at Atchafalaya River, were followed in a few hours by heavy rains.

I was with the first troops that passed down the river (Herron's Division, Thirteenth Army Corps), after the surrender of Vicksburg, to Port Hudson. We found it very muddy there (July), and also at Yazoo City, when taken by our troops, July 12, 1863. Everybody remembers that there was no difficulty in keeping *moist* at Vicksburg.

. . . .

Soon after we crossed the Boston Mountains (Arkansas) we found a light breeze blowing against the mountains from the opposite side. We had some artillery firing—say thirty or forty rounds—near Lee's Creek, early in the morning, with a clear sky. Here I remember that it was urged by some of our officers that artillery should not be used on the small number of the enemy's cavalry that were in front of us, for the reason that *it would bring on rain*, and thereby retard us in pursuit of the enemy. We got the rain in less than two hours. After the firing after the capture of Van Buren also we got rain in a few hours.

. . . .

It is possible that I know of an instance where there was heavy firing that was not followed by rain, and that the matter may have escaped my notice.

There are other instances where I know it did occur, but deem it unnecessary to cite them, as I have given you the cases of most importance, and which attracted my attention.

. . . .

Truly yours,

(*General*) J. McNulta.

Hiram, O., Oct. 28, 1870.

Dear Sir: In answer to yours of the 22d, I have to say that, while I did not take such observations as a scientific experiment requires, I did observe the frequent occurrence of heavy showers very soon after the battles in our late war. It was a matter much talked of in the army, and there was a general impression that the atmospheric disturbances produced by heavy cannonading hastened or created showers. I remember that heavy showers followed after the battles of Shiloh, Stone River, Shelbyville, and Chickamauga. But while these coincidences are curious and interesting, they are chiefly valuable from the fact that they challenge the attention of scientific men, and may lead to a discovery of the causes which will prove valuable to our knowledge of meteorology.

Very truly yours,

(*General*) J. A. Garfield.

The occurrences of the phenomenon of rain after battles were far too regular to be explained as simply coincidences, and, taken with the similar occurrences during the Mexican War and those in other foreign countries, constitute almost unquestionable proof of Mr. Powers's theory that rain can be and is produced by the concussions of cannonading.

Believing that the subject of artificial rainfall offered the possibilities of immense benefit to mankind, Mr. Powers purposed to interest the public in the matter sufficiently to obtain an

investigation by the government. And to secure this end he spent a large part of his time and income for over twenty years, influenced only by motives of philanthropy and expecting no personal benefits, as may be seen from the following extract from his book published in 1870: "The art of regulating the weather to some extent, if such an art should ever be acquired, is not one on which a patent could ever be obtained, nor would the business be one in which a monopoly could ever be exercised by an individual. . . . The experiments, when made, as eventually they surely will be, should be made at the public expense, for it is the public who would be benefited in the event of their success."

As early as 1874 a number of public men, including General William T. Sherman, General James A. Garfield, General John A. Logan, the Hon. C. B. Farwell, and others, became greatly interested in the project of producing rain by cannon-firing; but the expense which it was estimated would be entailed by the first experiments was so great that Congress took no action in the matter. The following estimate of the cost of the first two experiments was made by Mr. Powers, who proposed that two hundred siege-guns, which lie idle in the United States arsenal at Rock Island, Ill., be taken to a suitable locality in the West, and one hundred rounds be fired from them in each operation:

ESTIMATE.

Mounting 200 siege-guns, at $10 each	$2,000
Railway transportation for same, at $40 each	8,000
40,000 blank cartridges, at $2.50 each	100,000
50 tons of hay for wadding, at $12 per ton	600
10,000 electric primers, at $150 per M	1,500
Electric batteries and insulated wire	500
Services of 10 men, 26 days, at $2.50 per day	650
Services of 600 men, 26 days, at $1.50 per day	23,400
Rent of ground for experiments	250
Return transportation of guns to arsenal	8,000
Dismounting and putting guns away at arsenal	2,000
	$146,900
Add 10 per cent. for contingencies	14,690
Total	$161,590
Estimated cost of each experiment	80,795

Of course, if the Department of Agriculture had a regular system of properly equipped stations established throughout the West, the cost of an operation would be greatly diminished, but even then a good rain produced according to Mr. Powers's plan would cost not less than $20,000.

In 1880 General Daniel Ruggles, a resident of Fredericksburg, Va., suggested that, instead of the use of cannon on the ground, the firing of explosives raised high into the upper air strata

by means of balloons be employed. General Ruggles obtained a patent upon this plan, although a description of the same scheme had been published throughout the country several years before, being copied from a New Zealand newspaper, the Mimmora *Star*, in which the following item appeared in the fall of 1876: "Ferdinand Hatermann has been promulgating a new scheme in Horsham for producing rain. He asks that the district join in constructing a number of balloons seven feet in diameter. He proposes to fill these with sufficient gas to carry them into the regions of the rainy clouds, and in each of the balloons a canister of powder. When sufficiently high in the air, he would light them by means of fuse, and the explosion, say of a score of charges going off at once in the midst of the rainclouds, would, he thinks, break them. Whether anything more than smoke would result remains to be proved."

By this plan of raising the explosives used and discharging them among the currents which it is desired to affect, great economy of force is obtained, and the expense of producing the effect which a great battle would produce upon the upper-air currents is very much diminished.

In 1890 the Hon. C. B. Farwell and others who were interested in the subject brought the matter before Congress and obtained an appropriation of $2,000 for use by the Department of Agriculture in investigating the possibilities of the artificial production of rainfall, and the last Congress added $7,000 to this amount for a series of practical experiments. While the matter was before Congress, Senator C. B. Farwell, Secretary of Agriculture J. M. Rusk, and others interested, consulted, concerning the best methods and materials to be employed, with Dr. Claud O. O. Rosell, a chemist of the Patent Office, and the writer, who proposed that, instead of weighting down the balloons employed with a load of dynamite or other explosives, the balloons themselves be inflated with a highly explosive gas, such as a composition of hydrogen in two parts and oxygen one part, which mixture produces one of the most violent explosives known to science, and by employing which smaller balloons can be used, saving largely on the expense of apparatus and also on the cost of the explosives.

Later the writer consented to a request from the friends of the project that he take personal charge of the investigations and experiments, and was appointed a special agent of the Department

of Agriculture for that purpose. Several months were spent in preliminary investigations of the novel subject, and in planning and constructing apparatus, devising methods of operation, and gathering the requisite materials.

On the fifth day of August our party arrived at Midland, Texas, a small station on the Texas and Pacific Railway, situated on the Llano Estacado, or Staked Plains, in a region which had been suffering from a severe drought of several months' duration, and a lack of good rains for several years. A drive of twenty-five miles over the dry prairie, bearing little vegetation but scattered clumps of grass and low mesquite bushes, with here and there a cactus, brought us to the "C" Ranch, where, by the invitation of the owner, Mr. Nelson Morris, of Chicago, the first series of experiments were to be performed. The ranch is a typical Texan ranch of some 300,000 acres, supporting about 15,000 cattle and employing twenty cowboys. Our party, which included Dr. Claude Rosell, Mr. Edward Powers, Professor George E. Curtis, of the Smithsonian Institution, Mr. John T. Ellis, of Oberlin College, and five other specialists and assistants, was very comfortably quartered at the ranch-house, and every facility was afforded which the ranch possessed for carrying on our work. Nevertheless, a number of very serious difficulties and obstacles were encountered, some of which could not be easily surmounted. Chief among these may be mentioned, first, the remoteness of the ranch from any point where necessary supplies could be obtained; second, the very heavy winds which blow over the plains of western Texas almost constantly at a velocity of eighteen to twenty-five miles per hour, and render the manipulation of balloons a task of great difficulty; third, the strongly alkali drinking water obtained from the wells of the Staked Plains, which placed nearly every member of the expedition on the sick-list at various times, in spite of the fact that all the drinking water was treated with acids to precipitate the alkali or counteract its effect.

However, in spite of these difficulties a series of experiments were performed which, if they were not on quite so extensive a scale as will be employed in a few weeks in a locality where the conditions are less adverse, yet yielded results that were as interesting and valuable as could be expected from the first experiments under any conditions.

Our party is now temporarily scattered, and the specialists

who had charge of the investigations in the different lines have not yet had time to send in their various reports, so that it is not possible at this early date to make a report which will be of much scientific value; but a simple description of the operations and statement of the results can be given, which will be of much interest to the general reader.

We began operations with the following apparatus and materials: Sixty-eight explosive balloons 10 and 12 feet in diameter, having a capacity of 525 and 940 cubic feet each, respectively; three large balloons for making ascensions; 20,000 pounds of iron borings and 16,000 pounds of sulphuric acid, together with generators and fittings for manufacturing 50,000 cubic feet of hydrogen gas; 2,500 pounds of powdered chlorate of potash; 600 pounds of binoxide of manganese, with fifty retorts and suitable furnaces and fittings for generating 12,000 cubic feet of oxygen gas.

Material for making 100 strong cloth-covered kites was also brought from the East, as well as the ingredients for manufacturing several thousand pounds of rackarock powder and other high explosives. The party was also well supplied with electrical and meteorological instruments and apparatus.

The plan of operation was somewhat as follows: Three lines were to be formed, each some two miles in length, and placed about one-half mile apart. The first line to the windward was to consist of a large number of ground batteries, where heavy charges of dynamite and rackarock powder would be fired at frequent intervals. The next line to the rear was to consist of a number of kites flown to a considerable height by electric wires, bearing dynamite cartridges suspended from them, to be fired high in the air. The third and main line was to consist of explosive balloons which would produce terrific "air-quakes" at intervals of one to two hours throughout the day or during the continuance of the operation. In actual practice at the "C" Ranch, the first line of explosives was operated as proposed, and on days when the other lines were not in operation explosions were made along this line to keep the weather in an unsettled state. The kites were found to be very difficult of operation in the prevailing high winds, which were constantly breaking the sticks of the kites or parting the electric wires by which they were flown. This line was therefore not operated to the extent pro-

posed. The balloon line was carried out as planned, though the explosions were separated by somewhat greater intervals than were at first intended. The purpose was to imitate the effects of a great battle as nearly as possible, and in this I consider that we succeeded admirably.

The first operation was made on August 9. At this time the balloon apparatus had not been set up, and only the first line of ground explosions was brought into action. The ground batteries were operated for about an hour, beginning at 5 P.M. August 9, and reopened again for a shorter time at about 7 P.M. The weather was clear on the 9th, and the barometer stood at its normal height at 7 P.M. At noon of the 10th clouds began to gather directly over the ranch, and during the afternoon and the evening a very heavy rain fell,—nearly two inches,—transforming the roadways into rushing torrents and every hollow of the prairie into a small lake.

The next important operation was performed on August 18; the explosions having been begun on the evening previous, a large quantity of oxyhydrogen gas was used in the balloon explosions, while the ground batteries were kept in almost constant action for twelve hours. The morning had dawned clear and beautiful, and neither the appearance of the atmosphere nor the readings of the instruments gave any indication of aught but the fairest weather. This state of the weather continued until late in the afternoon, when heavy clouds gathered and *formed* in the south and west, and at 5 P.M. the operators of the ground batteries, which had kept up their roar until that time, were forced to run for shelter through a drenching rain, which fell in torrents for two and a half hours over the entire southern and eastern portion of Andrews County and most of Midland County and those to the south and west of it.

Late in the evening the writer drove in to Midland Station, a distance of 25 miles, and it is safe to say that six or eight miles of the road traversed was flooded under four to forty inches of water.

The final operation of this series of experiments was begun at 11 A.M. on the 25th day of August. At 3:30 P.M. of that day the barometric curve indicated a pressure of 26.93 inches, which is slightly below the normal for that hour at this elevation and locality, where the barometer generally reads "very dry." The wet- and dry-bulb psychrometer indicated a relative humidity of only 16, with the dew-point at 42 degrees.

The wind blew from the southeast (the usual direction) at a velocity of 18.8 miles per hour. The sky was clear, except for a few very light, scattered cumulus clouds, which were estimated, by the movements of the balloons, to be at a height of more than two and one-half miles.

Seven balloons, mostly of the large size, were sent up in this operation. Two 10-foot balloons were exploded by means of electric cable at a height of 1,000 feet, but the explosions of the larger balloons were too terrific to be risked at so close a proximity, and they were therefore fitted with fuses timed for two to six minutes and allowed to attain altitudes of from one to three miles before exploding.

The manner of operating the balloons was to fill them first to one-third their capacity by attaching them by pipes to a number of retorts containing chlorate of potash and a small quantity of binoxide of manganese. When these retorts were passed through the flames of gasoline furnaces set up in a large adobe workshop, the potash, being decomposed by the heat, gave off oxygen very rapidly. The balloon was then attached to the hydrogen generators and the inflation was completed with hydrogen. The hydrogen apparatus consists of three large tanks half full of water, with half a ton of iron borings in the bottom, into which sulphuric acid is slowly decanted. The acid rapidly decomposes the water into its gaseous elements and the iron takes up the oxygen, leaving the hydrogen free to pass through a wash-barrel into the balloon.

While the balloons were being filled and exploded a tremendous "cannonading" was in progress all along the ground batteries, and late into the night this firing was continued along a line a mile and a half in length.

At 11 P.M. the firing ceased, and our weary party immediately retired for the night. At 3 A.M., however, the heavy rolling of thunder disturbed the sleepers, and, looking out to the west and north, heavy banks of cloud were seen advancing, almost constantly lighted by most brilliant lightning. An hour later the rain began to fall in torrents on the ranch, and did not cease till 8 A.M. The northern portions of this county received the most thorough watering they have had for the past three years, and the reports from incoming cowboys indicate that the storm extended over many hundreds of square miles.

Besides these three heavy storms which occurred after the principal operations, not less than nine showers of much less importance fell during the sixteen days of our experiments; a most extraordinary occurrence in this locality, and especially at this season of the year. That these results were not produced at an excessive expense of material may be seen from the fact that in the entire series of experiments only two tons of iron, one ton of acid, one-fourth ton of potash and manganese, and one ton of rackarock powder and other explosives were consumed, none of which are expensive materials.

In the opinion of the writer the experiments clearly demonstrate—

First, That the concussions from explosions exert a marked and practical effect upon the atmospheric conditions in producing or occasioning rainfall, probably by disturbing the upper currents.

Second, That when the atmosphere is in a "threatening" condition—which is frequently the case in most arid regions without any rain resulting—rain can be caused to fall almost immediately by jarring together the particles of moisture which hang in suspension in the air. This result was repeatedly effected during our operations, the drops sometimes commencing to fall within twelve seconds from the moment of the initial explosion.

It also seems probable to the writer that the immense amount of frictional electricity generated by the concussions and the mingling of opposing currents of air may have considerable influence in the formation of storm-centres by producing a polarized condition of the earth and air, and so creating a magnetic field which may assist in gathering and so condensing the moisture of the surrounding atmosphere.

Altogether, considering the great difficulties under which we labored, the results of our first experiments have been exceedingly gratifying and encouraging to the advocates of the theory that rain can be produced at will by artificial means, and the further tests of the theory which will soon be made at El Paso, Texas, will be watched with great interest.

ROBERT G. DYRENFORTH.

TO THE uncritical observer the possible achievements of invention and discovery seem boundless. Half a century ago no idea could have appeared more visionary than that of holding

communication in a few seconds of time with our fellows in Australia, or having a talk going on *viva voce* between a man in Washington and another in Boston. The actual attainment of these results has naturally given rise to the belief that the word "impossible" has disappeared from our vocabulary. To every demonstration that a result cannot be reached the answer is, Did not one Lardner, some sixty years ago, demonstrate that a steamship could not cross the Atlantic? If we say that for every actual discovery there are a thousand visionary projects, we are told that, after all, any given project may be the one out of the thousand.

In a certain way these hopeful anticipations are justified. We cannot set any limit either to the discovery of new laws of nature or to the ingenious combination of devices to attain results which now look impossible. The science of to-day suggests a boundless field of possibilities. It demonstrates that the heat which the sun radiates upon the earth in a single day would suffice to drive all the steamships now on the ocean and run all the machinery on the land for a thousand years. The only difficulty is how to concentrate and utilize this wasted energy. From the standpoint of exact science aërial navigation is a very simple matter. We have only to find the proper combination of such elements as weight, power, and mechanical force. Whenever Mr. Maxim can make an engine strong and light enough, and sails large, strong, and light enough, and devise the machinery required to connect the sails and the engine, he will fly. Science has nothing but encouraging words for his project, so far as general principles are concerned.

Such being the case, I am not going to maintain that we can never make it rain.

But I do maintain two propositions. If we are ever going to make it rain, or produce any other result hitherto unattainable, we must employ adequate means. And if any proposed means or agency is already familiar to science, we may be able to decide beforehand whether it is adequate. Let us grant that out of a thousand seemingly visionary projects one is really sound. Must we try the entire thousand to find the one? By no means. The chances are that nine hundred of them will involve no agency that is not already fully understood, and may, therefore, be set aside without even being tried. To this class belongs the project of producing rain by sound. As I write, the daily journals

are announcing the brilliant success of experiments in this direction; yet I unhesitatingly maintain that sound cannot make rain, and propose to adduce all necessary proof of my thesis. The nature of sound is fully understood, and so are the conditions under which the aqueous vapor in the atmosphere may be condensed. Let us see how the case stands.

A room of average size, at ordinary temperature and under usual conditions, contains about a quart of water in the form of invisible vapor. The whole atmosphere is impregnated with vapor in about the same proportion. We must, however, distinguish between this invisible vapor and the clouds or other visible masses to which the same term is often applied. The distinction may be very clearly seen by watching the steam coming from the spout of a boiling kettle. Immediately at the spout the escaping steam is transparent and invisible; an inch or two away a white cloud is formed, which we commonly call steam, and which is seen belching out to a distance of one or more feet, and perhaps filling a considerable space around the kettle; at a still greater distance this cloud gradually disappears. Properly speaking, the visible cloud is not vapor or steam at all, but minute particles or drops of water in a liquid state. The transparent vapor at the mouth of the kettle is the true vapor of water, which is condensed into liquid drops by cooling; but after being diffused through the air these drops evaporate and again become true vapor. Clouds, then, are not formed of true vapor, but consist of impalpable particles of liquid water floating or suspended in the air.

But we all know that clouds do not always fall as rain. In order that rain may fall the impalpable particles of water which form the cloud must collect into sensible drops large enough to fall to the earth. Two steps are therefore necessary to the formation of rain: the transparent aqueous vapor in the air must be condensed into clouds, and the material of the clouds must agglomerate into raindrops.

No physical fact is better established than that, under the conditions which prevail in the atmosphere, the aqueous vapor of the air cannot be condensed into clouds except by cooling. It is true that in our laboratories it can be condensed by compression. But, for reasons which I need not explain, condensation by compression cannot take place in the air. The cooling which results in the formation of clouds and rain may come in two ways.

Rains which last for several hours or days are generally produced by the intermixture of currents of air of different temperatures. A current of cold air meeting a current of warm, moist air in its course may condense a considerable portion of the moisture into clouds and rain, and this condensation will go on as long as the currents continue to meet. In a hot spring day a mass of air which has been warmed by the sun, and moistened by evaporation near the surface of the earth, may rise up and cool by expansion to near the freezing-point. The resulting condensation of the moisture may then produce a shower or thunder-squall. But the formation of clouds in a clear sky without motion of the air or change in the temperature of the vapor is simply impossible. We know by abundant experiments that a mass of true aqueous vapor will never condense into clouds or drops so long as its temperature and the pressure of the air upon it remain unchanged.

Now let us consider sound as an agent for changing the state of things in the air. It is one of the commonest and simplest agencies in the world, which we can experiment upon without difficulty. It is purely mechanical in its action. When a bomb explodes, a certain quantity of gas, say five or six cubic yards, is suddenly produced. It pushes aside and compresses the surrounding air in all directions, and this motion and compression are transmitted from one portion of the air to another. The amount of motion diminishes as the square of the distance; a simple calculation shows that at a quarter of a mile from the point of explosion it would not be one ten-thousandth of an inch. The condensation is only momentary; it may last the hundredth or the thousandth of a second, according to the suddenness and violence of the explosion; then elasticity restores the air to its original condition and everything is just as it was before the explosion. A thousand detonations can produce no more effect upon the air, or upon the watery vapor in it, than a thousand rebounds of a small boy's rubber ball would produce upon a stone wall. So far as the compression of the air could produce even a momentary effect, it would be to prevent rather than to cause condensation of its vapor, because it is productive of heat, which produces evaporation, not condensation.

The popular notion that sound may produce rain is founded principally upon the supposed fact that great battles have been followed by heavy rains. This notion, I believe, is not confirmed

by statistics; but, whether it is or not, we can say with confidence that it was not the sound of the cannon that produced the rain. That sound as a physical factor is quite insignificant would be evident were it not for our fallacious way of measuring it. The human ear is an instrument of wonderful delicacy, and when its tympanum is agitated by a sound we call it a "concussion," when, in fact, all that takes place is a sudden motion back and forth of a tenth, a hundredth, or a thousandth of an inch, accompanied by a slight momentary condensation. After these motions are completed the air is exactly in the same condition as it was before; it is neither hotter nor colder; no current has been produced, no moisture added.

If the reader is not satisfied with this explanation, he can try a very simple experiment which ought to be conclusive. If he will explode a grain of dynamite, the concussion within a foot of the point of explosion will be greater than that which can be produced by the most powerful bomb at a distance of a quarter of a mile. In fact, if the latter can condense vapor a quarter of a mile away, then anybody can condense vapor in a room by slapping his hands. Let us therefore try slapping our hands, and see how long we must continue before a cloud begins to form.

What we have just said applies principally to the condensation of invisible vapor. It may be asked whether, if clouds are already formed, something may not be done to accelerate their condensation into raindrops large enough to fall to the ground. This also may be the subject of experiment. Let us stand in the steam escaping from a kettle and slap our hands. We shall see whether the steam condenses into drops. I am sure the experiment will be a failure; and no other conclusion is possible than that the production of rain by sound or explosions is out of the question.

It must, however, be added that the laws under which the impalpable particles of water in clouds agglomerate into drops of rain are not yet understood, and that opinions differ on this subject. Experiments to decide the question are needed, and it is to be hoped that the Weather Bureau will undertake them. For anything we know to the contrary, the agglomeration may be facilitated by smoke in the air. If it be really true that rains have been produced by great battles, we may say with confidence that they were produced by the smoke from the burning powder rising into the clouds and forming nuclei for the agglom-

eration into drops, and not by the mere explosion. If this be the case, if it was the smoke and not the sound that brought the rain, then by burning gunpowder and dynamite we are acting much like Charles Lamb's Chinamen who practised the burning of their houses for several centuries before finding out that there was any cheaper way of securing the coveted delicacy of roast pig.

But how, it may be asked, shall we deal with the fact that Mr. Dyrenforth's recent explosions of bombs under a clear sky in Texas were followed in a few hours, or a day or two, by rains in a region where rain was almost unknown? I know too little about the fact, if such it be, to do more than ask questions about it suggested by well-known scientific truths. If there is any scientific result which we can accept with confidence, it is that ten seconds after the sound of the last bomb died away, silence resumed her sway. From that moment everything in the air—humidity, temperature, pressure, and motion—was exactly the same as if no bomb had been fired. Now, what went on during the hours that elapsed between the sound of the last bomb and the falling of the first drop of rain? Did the aqueous vapor already in the surrounding air slowly condense into clouds and raindrops in defiance of physical laws? If not, the hours must have been occupied by the passage of a mass of thousands of cubic miles of warm, moist air coming from some other region to which the sound could not have extended. Or was Jupiter Pluvius awakened by the sound after two thousand years of slumber, and did the laws of nature become silent at his command? When we transcend what is scientifically possible, all suppositions are admissible; and we leave the reader to take his choice between these and any others he may choose to invent.

One word in justification of the confidence with which I have cited established physical laws. It is very generally supposed that most great advances in applied science are made by rejecting or disproving the results reached by one's predecessors. Nothing could be farther from the truth. As Huxley has truly said, the army of science has never retreated from a position once gained. Men like Ohm and Maxwell have reduced electricity to a mathematical science, and it is by accepting, mastering, and applying the laws of electric currents which they discovered and expounded that the electric light, electric railway, and all other applications of electricity have been developed. It is by applying and

utilizing the laws of heat, force, and vapor laid down by such men as Carnot and Regnault that we now cross the Atlantic in six days. These same laws govern the condensation of vapor in the atmosphere; and I say with confidence that if we ever do learn to make it rain, it will be by accepting and applying them, and not by ignoring or trying to repeal them.

How much the indisposition of our government to secure expert scientific evidence may cost it is strikingly shown by a recent example. It expended several million dollars on a tunnel and water-works for the city of Washington, and then abandoned the whole work. Had the project been submitted to a commission of geologists, the fact that the rock-bed under the District of Columbia would not stand the continued action of water would have been immediately reported, and all the money expended would have been saved. The fact is that there is very little to excite popular interest in the advance of exact science. Investigators are generally quiet, unimpressive men, rather diffident, and wholly wanting in the art of interesting the public in their work. It is safe to say that neither Lavoisier, Galvani, Ohm, Regnault, nor Maxwell could have gotten the smallest appropriation through Congress to help make discoveries which are now the pride of our century. They all dealt in facts and conclusions quite devoid of that grandeur which renders so captivating the project of attacking the rains in their aërial stronghold with dynamite bombs

S. NEWCOMB.